This paper is part of the following report:

TITLE: Nanostructures: Physics and Technology International Symposium
[8th] Held in St. Petersburg, Russia on June 19-23, 2000 Proceedings

To order the complete compilation report, use: ADA407315

Fractional charge in transport through a 1D correlated insulator of finite length

V. V. Ponomarenko

Dept. of Physics and Astronomy SUNY at Stony Brook, NY 11794, USA
Ioffe Physico-Technical Institute, St Petersburg, Russia

Abstract. Transport between two Fermi liquid reservoirs through a one channel wire of length L is examined when the 1D electron system has an energy gap $2M$: $M > T_L \equiv v_c/L$ induced by the interaction in its charge mode (v_c: charge velocity in the wire). In the spinless case transformation of reservoir electrons into solitons of fractional charge entails a crossover from a Fermi liquid regime of integer charge transfer below the crossover energy $T_x \ll T_L$ to the insulating one of the fractional charge transfer in the current vs voltage, conductance vs temperature, and the shot noise. Similar behavior is predicted for a spin Mott insulator of filling factor $v = n/(2m')$ $(n, m'$: positive integer).

Introduction

Fractional charge (FC) is one of the central issues in the physics of strongly correlated electronic systems. However its direct observation in transport through these systems involves transfer of FC between the Fermi liquid (FL) source and drain reservoirs. Since the charge carriers of the reservoirs are electron-like quasiparticles one can doubt to which extent this transfer is possible even between the ideal infinite reservoirs. Recently a few remarkable experiments in transport through 1D [1] and 2D [2] systems have been attempted to measure the FC of elementary excitations. In the 2D systems of incompressible Fractional Quantum Hall liquid (FQHL) the quantum transport is dominated by the edge mode, which has been described [3] as a chiral Tomonaga–Luttinger liquid (TLL). Another realization of TLL is a metallic phase of 1D interacting electrons in the quantum wire. Therefore it had been expected that the same model describes both transports despite the different origin of their effective interaction. The above experiments however have revealed a principal difference. It has been attributed [4] to mechanisms of mutual transformation of the fractionally charged excitations into electrons at the interfaces between the strongly correlated system and the (FL) reservoirs.

1D transport model

In this work we examine transport through the wire of length L when its 1D electrons are in a Mott insulating phase characterized by the gap $2M \gg v_c/L \equiv T_L$ in the energy spectrum (v_c: charge velocity in the wire). This situation has been approached in experiment by Kouwenhoven *et al.* [5] who built a periodic potential into a 1 channel wire of spinless electrons. Varying the electron density with a gate voltage they observed suppression of the conductance at integer and some rational fillings. Recently Tarucha *et al.* has succeeded [6] in introducing a shorter period potential. This allows Umklapp scattering and, hence, insulating behavior due to correlations at some rational fillings $v = n/m$. In the spinless case this is a 1D charge density wave insulator (CDW). It is described by a sin-Gordon model whose carriers are (anti)solitons of FC $q = 1/m \le e \equiv 1$ and mass M. For the finite length

insulator, however, the transport is described by an inhomogeneous sin-Gordon model and involves mutual transformations between reservoir electrons and CDW (anti)solitons. The latter see the reservoirs as a slowly decaying interaction along the boundaries whose strength is proportional to q^2, meanwhile the electrons see the CDW condensate as a quantization of their phase at the boundaries, whose values $2\pi q \times integer$ relate to the CDW vacua. A general solution to this model is unknown. Below we concentrate on the low energy limit of $T \ll T_L < M$ (T: temperature) when the carriers in the wire are rare.

Solution and results

By applying an instant on technique the model reduces [7] through a Duality Transform to a point scatterer in a TLL whose solution is known. Behavior of the low temperature conductance is ruled by a scaling dimension of the tunneling operator $\bar{g} = q^2$. The latter is always relevant $\bar{g} < 1$ for the correlated insulator opposed to the band insulator where it is marginal. With lowering temperature/voltage the mutual transformations between reservoir electrons and CDW (anti)solitons eventually produce a crossover at some energy $T_x = cst\sqrt{T_L M}\exp[-\varepsilon/(1-\bar{g})] \ll T_L$, $\varepsilon = \sqrt{M^2 - (q\mu)^2}/T_L$, ($\mu$: chemical potential) in the transport from an insulating regime of FC transfer to a FL regime of integer charge current. This conclusion is confirmed by analysis of the shot noise, which reveals that above the crossover the charge of carriers is q. It takes the same values as FC in FQHL theory. Meanwhile below T_x it recovers an integer electron value because the interaction induced by the interface couples tunneling (anti)solitons in groups. The correlated insulator conductance recovers its free electron value in the absence of impurities below the crossover at the temperature T_x. The current versus voltage has its maximum at $V \approx T_x$ and a negative differential conductance above. Therefore the FC transfer is indicated in the transport experiments by the non-monotonic conductance vs temperature and current vs voltage below T_L. The inverse of T_x estimates the time during which the FC exists in the reservoirs. This conclusion complies with consideration of capacitance spectroscopy for the system where one of our reservoirs is changed into a metallic dot of charging energy E_c following [8]. In neglect of the one-electron level spacing of the dot smeared by a small temperature it may be shown that the fractional quantization of the charge emerges if $E_c/T_x > 1$.

This description of the CDW condensate is also applicable to the charge mode of electrons with spin at rational fillings of even denominator $v = 1/(2m') \times integer$. The above results just need redefinitions: $q = 1/m'$, $\bar{g} = q^2/2$. In particular, the charge q of the Mott–Hubbard insulator $v = 1/2$ is now 1. This marginality shows up in saturation of current as the voltage exceeds T_x [9].

References

[1] S. Tarucha, T. Honda and T. Saku, *Solid State Commun.* **94**, 413 (1995); A. Yacobi *et al.*, *Phys. Rev. Lett.* **77**, 4612 (1996).
[2] L. Saminadayar *et al.*, *Phys. Rev. Lett.* **79**, 2526 (1997); M. Reznikov *et al.*, cond-mat/9901150.
[3] X. G. Wen, *Phys. Rev. B* **43**, 11 025 (1991); *Phys. Rev. Lett.* **64**, 2206 (1990).
[4] V. V. Ponomarenko, *Phys. Rev. B* **52**, R8 666 (1995); V. V. Ponomarenko and N. Nagaosa, *Phys. Rev. B* **60**, 16 865 (1999).
[5] L. P. Kouweenhoven *et al.*, *Phys. Rev. Lett.* **65**, 361 (1990).
[6] S. Tarucha, private communications.
[7] V. V. Ponomarenko and N. Nagaosa, *Phys. Rev. Lett.* **83**, 1822 (1999).
[8] K. Flensberg, *Phys. Rev. B* **48**, 11 156 (1993); K. A. Matveev, *Phys. Rev. B* **51**, 1743 (1995).
[9] V. V. Ponomarenko and N. Nagaosa, *Phys. Rev Lett.* **81**, 2304 (1998).